Instruments for the New Telephone Sets *

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Transmitters and receivers for use at subscribers' telephone stations have been designed which not only materially improve transmission but also simplify manufacture and facilitate maintenance. This paper discusses these improvements and describes some of the new design technique employed in their development.

As a result of continuous development work on transmitters and receivers for use at subscribers' telephone stations, new instruments have been designed which not only materially improve transmission but also embody features which simplify manufacture and facilitate maintenance. These instruments are now being produced for use in handsets, desk stands and wall sets in the Bell System.[1]

In many respects these instruments represent outstanding advances in transmission instrument design and performance. It is the purpose of this paper to discuss these improvements and to describe some of the new design technique employed in their development. The data presented will be confined almost entirely to physical measurements which serve to define the performance characteristics of the instruments. The interpretation of these data in terms of their relationship to the characteristics of associated apparatus and their overall reaction on transmission in the telephone plant is covered by a companion paper dealing with the transmission features of the new sets.[2]

Handset Applications

The new transmitter unit with an adapter was first introduced in 1934 as a replacement for the earlier type of handset transmitter.[3] There are now about five million of these transmitters in use in the plant of the Bell System. While experience has shown that they effect an outstanding improvement in performance they do not take full advantage of the possibilities of the unit type of construction from the standpoint of simplification, owing to the fact that a number of additional parts are required to mount the unit on the existing type of handset handle. The advantages of the unit type of instrument have been realized in a new design of handset introduced during 1937, about a million of which have been produced. This handset is shown

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with the new combined set in the photograph, Fig. 1, and in cross-section on Fig. 2.

In designing this handset every effort has been made to obtain the maximum degree of simplicity consistent with the electrical requirements involved and at the same time to secure an attractive design which harmonizes with the other station apparatus on the subscriber's premises. Only three phenol plastic parts are employed; namely, the

Fig. 1—Handset and desk stand equipped with the new instruments.

handle and the transmitter and receiver caps. In designing these parts particular attention has been paid to providing adequate cross-sections at the points of maximum stress and to distributing the weight so as to reduce to a minimum the breaking moments which are developed when the handset is dropped. The transmitter and receiver caps serve the dual purpose of holding the units in place and providing mechanical protection. In addition they thoroughly insulate the user from all the metal parts which are included in the electrical circuit. Both caps have smooth surfaces which can be readily cleaned. As will be pointed out later, the grid of the receiver cap also has a transmission function and plays an important part in determining the response in the upper frequency range. Spring contacts are provided to facilitate the assembly of the units in the handle. This operation is further facilitated by the fact that specific alignment of the units

Fig. 2—Cross-section of the handset.

and the caps relative to the handle is unnecessary. The spacing between the transmitter and receiver is such that the handset can be used with the existing type of desk mounting as well as with the new combined set.

Desk Stand and Wall Set Applications

The photograph, Fig. 1, also shows the new transmitter and receiver unit adapted to desk stand and wall set use. Cross-sections of these instruments are shown on Fig. 3. The faceplate, mouthpiece and pro-

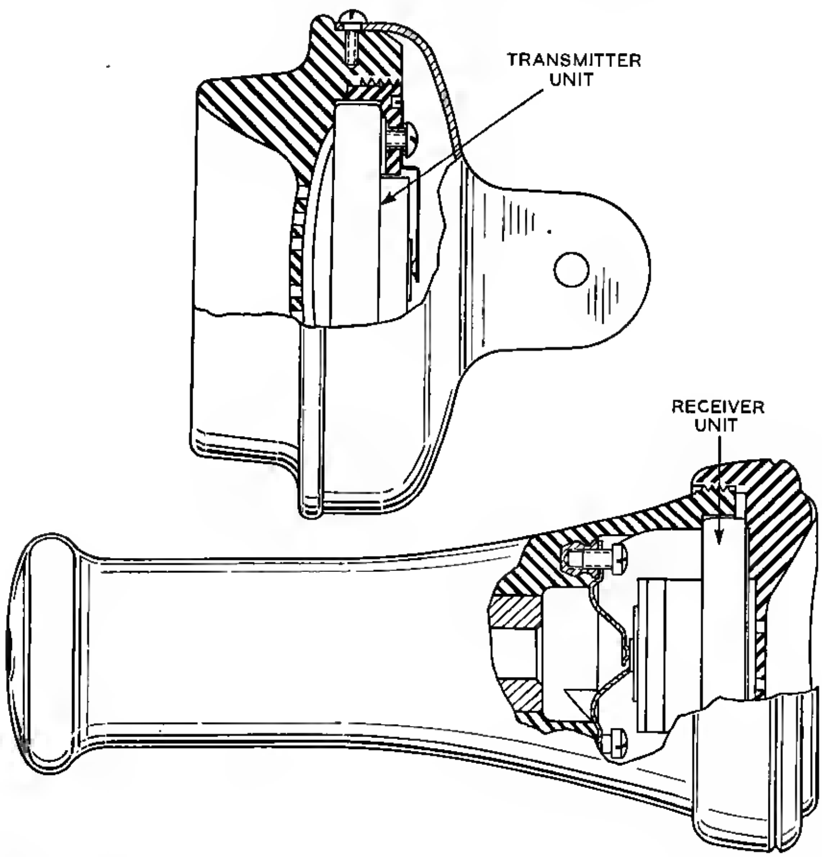

Fig. 3—Cross-sections of the transmitter and receiver for desk stands and wall sets.

tective grid of the transmitter are combined in one phenol plastic part which is so designed as to reduce cavity resonance to a minimum and provide response characteristics essentially the same as those of the handset transmitter. On the other hand, the mouthpiece is sufficiently

prominent to encourage the user to talk directly into it and in this way reduce the losses which often result when flush type faceplates are employed with desk stand and wall set instruments. A phenol plastic part, equipped with contact springs, holds the unit tightly in the faceplate and provides electrical connections.

As in the handset the unit of the receiver is held in place by the cap. Springs are provided in the shell for bringing out the electrical connections. A metal insert adds sufficient weight to meet the switchhook requirements of the existing sets. The phenol plastic parts of both the receiver and transmitter are so designed as to insulate thoroughly the units and minimize breakage.

Transmitter Unit

The new transmitter unit is of the "direct action" type, that is, one in which the movable electrode serves the dual purpose of contact and pressure surface. As is shown by Fig. 2, this electrode is mounted at the center of a diaphragm of thin aluminum alloy formed into a shallow cone and ribbed to add rigidity. "Books" of thin impregnated paper mounted in a recess in a die-cast frame provide a resilient support for the edge of the diaphragm. The fixed electrode is held in place in the frame by a threaded ring and is insulated from the frame by a phenol fibre washer and a ceramic insulator which also forms one of the surfaces of the carbon chamber. The active surfaces of both electrodes are gold plated. A silk annulus clamped at its outer edge between the ceramic insulator and the frame and its inner edge between the movable electrode and the diaphragm forms a resilient closure for the carbon chamber. Electrical connection between the movable electrode and the frame is provided by means of metal strips of low stiffness. Provision is made for machine filling the carbon chamber through a hole in the fixed electrode and closing this hole by means of a cap which crimps over a projecting shoulder. The exposed surfaces of the cap and the threaded ring are silver plated and form the contact surfaces for the electrical connections. A moisture-resistant membrane protects the internal parts of the unit from the effects of condensed moisture from the breath. This membrane is clamped at its outer edge between a protective grid of perforated metal and the frame. A thin metal ferrule fastens the grid to the frame. The exposed parts of the unit are anodically finished to resist corrosion.

In addition to being simpler than the earlier transmitter and hence less difficult to produce, the new transmitter unit has characteristics such that:

1. Its performance is less affected by angular position.
2. There is less aging under the conditions encountered in service.
3. The electrical output is higher and the response more uniform.
4. The modulation products resulting from non-linearity are materially reduced.

Effect of Angular Position.—In order to insure good contact between the carbon granules and the diaphragm in the positions in which the handset is most likely to be held in service, the carbon chamber of the earlier transmitter was placed in front instead of the conventional location in back of the diaphragm.[3] The positional characteristics of this transmitter were further improved by the use of a "barrier" type of variable resistance element in which the electrodes are stationary and form the walls of the carbon chamber, and in which the surface of the diaphragm in contact with the granules is insulated and serves only as means for changing the contact forces between the granules in response to the variations in sound pressure at the diaphragm surface. While this transmitter represented a distinct advance in handset performance from a transmission standpoint and was quite effective in reducing undesirable positional effects, particularly in the "horizontal face-up" position, it was somewhat complicated mechanically and involved the problem of providing a closure between the diaphragm and the adjacent electrode which would be sufficiently resilient to meet the transmission requirements and at the same time prevent carbon leakage. In addition, there was some degradation in quality when it was held in the "horizontal face-down" position where the carbon granules tended to fall away from the diaphragm. While this condition occurred only infrequently in service, it was one which it was considered desirable to eliminate if this could be accomplished without making the structure mechanically complex or difficult to manufacture or maintain. A tendency also was observed in the field for the resistance to increase sufficiently under certain conditions to react adversely on the operation of the associated signaling apparatus. Owing to the inherently small areas of the sound passages leading to the diaphragm the moisture condensed from the breath could not be excluded by a membrane without complicating the structure and adding sufficient mechanical impedance to impair transmission.

Following the introductory work on the barrier transmitter, an intensive study of the direct action type of carbon element was made to determine whether the limitations of the earlier structures of this type, which arose from the non-fluid character of the carbon, could be overcome. This study resulted in the transmitter unit shown on Fig. 2. This unit eliminates the undesirable features of the inverted type without sacrificing its desirable characteristics.

The electrode surfaces of the new transmitter unit are so proportioned and so spaced relative to each other that the important current paths shift their locations in the carbon mass with changes in angular position in a manner such that the mean effective pressures in the paths and the lengths of the paths result in substantially constant resistance in all positions. Furthermore, the components of the axial motion of the diaphragm effective in changing the contact forces in the paths are also such as to produce essentially constant modulation. Not only is the total resistance of the paths between the electrodes substantially

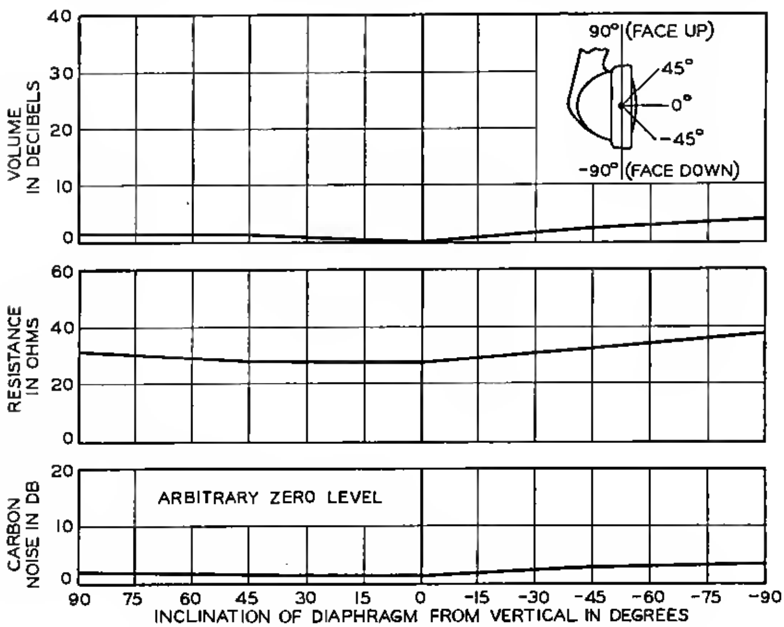

Fig. 4—Positional characteristics of the transmitter.

constant, but this resistance also is uniformly distributed between the individual contacts with the result that at no time does the contact potential rise to a value sufficiently high to produce objectionable carbon noise or "burning." These features result in resistance, volume efficiency and carbon noise characteristics which, as is shown by Fig. 4, are essentially independent of angular position.

Another and perhaps a more exacting criterion of the adequacy of a transmitter from the standpoint of its ability to function satisfactorily in all positions is the extent to which its transmission characteristics at normal speech intensities are adversely affected when immediately

preceded by loud speech. If a poorly designed transmitter is held in a position such that the carbon granules tend to fall away from the movable electrode when this test is applied, the non-fluid action of the carbon will prevent the reestablishment of contact with the electrode surface with the result that volume losses of as much as 20 db and a serious degradation in quality take place. Furthermore, these losses persist until the transmitter is jarred or moved about sufficiently to change the configuration of the granules. On the other hand, if the effect of the frictional forces within the granular mass has been taken fully into account in the design of the carbon element, these forces will not react in a manner such as to prevent good contact with the electrode following the large amplitude produced by loud speech and uniform volume and good quality will obtain at all times. The new transmitter meets this test with a substantial margin.

Carbon leakage is prevented in the new instrument without impairment of transmission by the resilient silk closure for the carbon container previously mentioned.

Aging.—Transmitter design has advanced to a stage where heating at the points of contact in the carbon element need no longer be an important source of aging. Therefore, such aging of the granular material as occurs in a well-designed instrument is limited almost entirely to that resulting from changes in the properties of the granules caused by abrasion of their surfaces when the transmitter is subjected to mechanical shocks such as occur when the handset is placed on the mounting. As in the case of the earlier transmitter, the new transmitter is machine filled [3] with the result that the motion of the granules and the resultant surface abrasion is reduced to a minimum.

The changes in resistance due to the residual aging have little adverse effect insofar as volume is concerned. In fact, the constants of most of the circuits in which the transmitter is used are such that an increase in resistance adds to rather than decreases the electrical output because of the greater amount of power supplied to the transmitter from the central office battery.

On the other hand, an increase in resistance, though small, may prove to be important in certain circuits where a critical relationship between transmitter resistance and the performance of associated apparatus exists. Under these conditions variations in transmitter resistance may result in failure of the associated apparatus to perform satisfactorily if certain limiting values of resistance are exceeded. In determining the limits to be placed on these values account must be taken of all the variables in the circuit in which the transmitter is connected. Obviously combinations of variables of this nature

cannot be dealt with on the basis of averages alone but must include some measure of their range, such, for example, as the standard deviation.[4] The available data indicate that average transmitter resistances and standard deviations which lie within the area bounded by the dotted curve, Fig. 5, will have no adverse effect on circuit

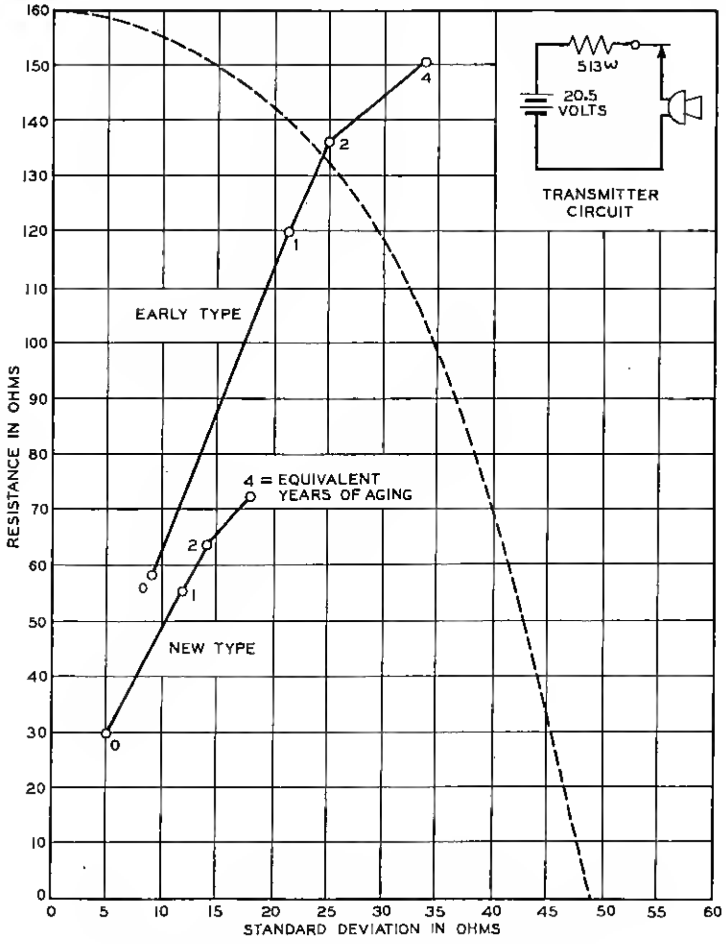

Fig. 5—Limiting values of transmitter resistance.

operation in the Bell System plant. This curve is based on certain marginal circuits of which there are a number in everyday use. An important transmitter resistance in determining the performance of associated apparatus in these circuits is the resistance during the period when the call is being established. This resistance is referred

to as the signaling resistance. As is shown by the solid curves the signaling resistance of the earlier type of transmitter after artificial aging by an amount considered to be the equivalent of four years in service falls outside the acceptable area. On the other hand, the resistance of the new type when aged and measured under identical conditions falls well within the limiting curve and hence not only requires less frequent replacement but also permits greater freedom in circuit design and plant layout.

Moisture condensed from the breath is an important factor in determining the life of a transmitter. A protective membrane is provided in the new transmitter unit which not only is highly moisture resistant but also results in no appreciable transmission impairment. The characteristics of the material employed in this membrane are such that it is not affected by the aging conditions encountered in service such, for example, as the alkaline reaction of water after it has been in contact with phenol plastic parts or tobacco ashes. The exposed metal parts are finished to resist the corrosive action of these agents.

Response.—Reducing the transmitter to an equivalent electrical circuit provides a useful means for analyzing its performance and determining the extent to which the individual parts contribute to its response. Such a circuit for the new unit is shown on Fig. 6.

While the diaphragm can be represented as a lumped mass for frequencies in the region below 3500 cycles per second, it is necessary to consider it as being composed of three masses coupled by stiffnesses in order to represent adequately its performance at higher frequencies. These masses consist of the central portion m_5, the ribbed intermediate portion m_2 and the outer portion m_4. The central portion includes the mass of the movable electrode and is coupled to the ribbed portion by the stiffness s_6 which in turn is coupled to the outer portion by the stiffness s_2. The paper books which support the edge of the diaphragm have a stiffness s_4 and a resistance r_4. Their mass is included in the mass of the outer portion of the diaphragm m_4. The internal resistances of the portions which form the coupling stiffnesses s_2 and s_6 are represented by r_2 and r_6 respectively. A hole is provided in the diaphragm to permit rapid equalization of low frequency pressures of high intensity and prevent damage to the diaphragm and other parts. The mass and resistance of this hole, m_3r_3, are so chosen that their effect on response is confined to frequencies below 300 cycles per second where the station circuit itself is relatively inefficient. The controlling stiffness, s_3, is that of the cavity between the diaphragm and the die-cast frame. As is to be expected the impedance of the carbon granules is a function of amplitude and frequency. However, for the purpose

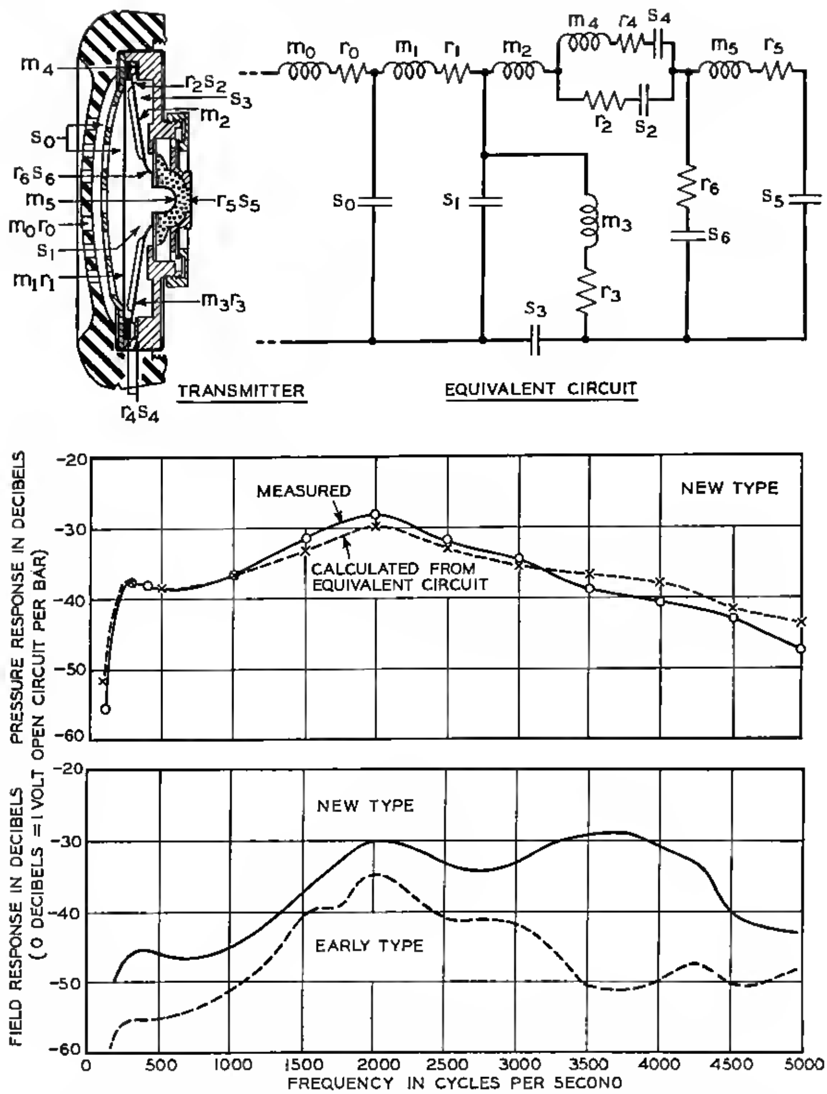

Fig. 6—Pressure and field response characteristics of the transmitter.

of this type of analysis, their impedance characteristics can be represented to a first approximation by a constant stiffness and resistance, r_6s_6. The mass of the carbon is lumped with that of the central portion of the diaphragm. The grid of the transmitter unit proper is provided for mechanical protection only and has holes large enough to have no reaction on response. When assembled in a handset or desk

stand a second grid of insulating material is added. The holes of this grid have a mass and resistance, m_0r_0, which must be taken into account in arriving at an overall picture of the factors affecting response. These holes are coupled to the moisture-resistant membrane, m_1r_1, by means of the stiffness s_0 of the enclosed cavity. The cavity stiffness, s_1, couples the membrane to the diaphragm.

There are two types of response frequency measurements in general use; namely, pressure response measurements in which a constant sound pressure is maintained at the face of the transmitter throughout the frequency range covered by the test, and field response measurements in which a sound field of constant intensity is established at each frequency before inserting the test transmitter. Pressure response is used principally for purposes of analysis whereas field response usually affords a better measure of the performance of the transmitter under the conditions of actual use.

The pressure response of the new transmitter measured with a constant sound pressure at the grid, and the response computed from the equivalent circuit are shown on Fig. 6. The transmitter used in this test was artificially aged by an amount equivalent to two years of service in order to simulate more nearly plant conditions. While the computed curve departs slightly from the measured curve at certain frequencies, due to the inadequacy of some of the basic assumptions, such as those which were made relative to the impedance of the granular carbon, the agreement in general is so good as to provide a powerful tool for predetermining the response characteristics of transmitters under development and a useful method for evaluating the reaction of one element of the transmitter on another. Reducing the transmitter to an equivalent electrical circuit also has proved invaluable in determining the causes of variations in transmitter performance observed during manufacture.

As previously mentioned, the response characteristics of a transmitter under conditions of actual use may differ from those obtained with a constant pressure at its face. In general this is due to the fact that the diffraction effect of the transmitter as an obstacle in the sound field has not been taken into account. While not as readily predetermined as the pressure response, the field response can be easily measured by inserting the transmitter in a sound field of constant intensity. An artificial voice [5] is used in this measurement as a sound source and the electrical input is adjusted to maintain a constant sound pressure at the guard ring at each frequency before inserting the instrument under test. Response curves for the new and early types of transmitter obtained in this way also are shown in Fig. 6.

Both show rising characteristics in the region of 2000 cycles per second. While it is feasible to design a transmitter having a substantially flat field characteristic, experience has shown that the transmission obtained with a transmitter having a rising response in this frequency region more nearly approaches direct speech,[2] when used with a representative line and the new receiver, than that obtained with one having a more uniform field response.

Non-Linear Distortion.—A substantial reduction in non-linearity has been effected in the new transmitter unit.

It is a well-known fact that the slope of the input-output curve of most transmitters is not unity even for sound intensities other than

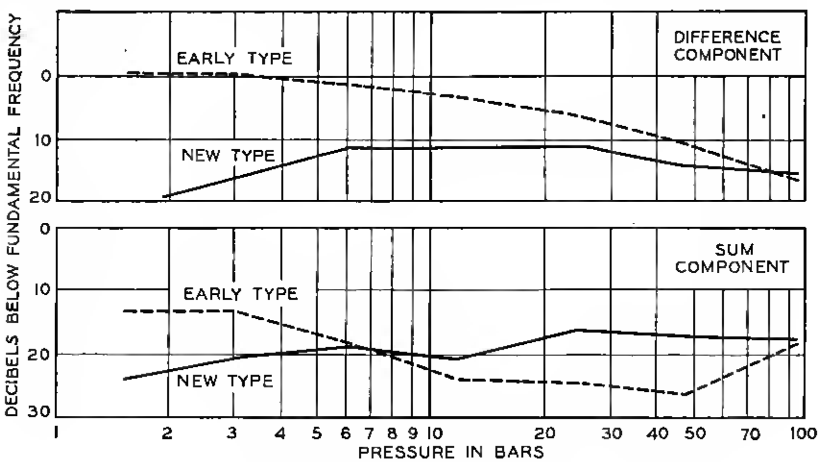

Fig. 7—Sum and difference components as a function of the intensity of the fundamental frequencies.

those at which overloading occurs. However, this departure from non-linearity does not entirely account for the modulation products developed when two frequencies are impressed on the transmitter. Measurements of the sum and difference components in the output of the new transmitter and the earlier transmitter for frequencies of 1500 and 1700 cycles per second are shown on Fig. 7. It will be noted that whereas the difference component produced by the earlier instrument is equal to the fundamental within the speech range, the sum and difference components are both 10 db or more below the fundamental at all the intensities measured in the case of the new unit.

A tendency for the difference component to be considerably more pronounced than the sum component in the case of the earlier transmitter is characteristic of all of the commercial instruments measured

during the development of the new unit. As previously mentioned, this cannot be fully explained by a non-linear relationship between input and output. The available data indicate that it is due to the manner in which the resistance changes cyclically when pressure waves of two frequencies are impressed simultaneously on the transmitter. Similar effects also have been observed in the microphonic action of carbon contacts themselves. Hence it is not unlikely that this is a fundamental characteristic of the carbon itself. If this proves to be true the extent to which an improvement can be effected in the performance of the transmitter will depend upon the ultimate control which can be exerted over the basic properties of the granular material.

Receiver Unit

The new receiver unit is of the bipolar permanent magnet type. The magnetic circuit consists of pole-pieces of 45 per cent permalloy, two straight bar magnets of remalloy and a permendur diaphragm.[6] The magnets are welded to the pole-pieces to form a unit which is mounted on projecting lugs on the die-cast frame. The coils are wound with enamel insulated wire interleaved with cellulose acetate. The pole tips project through a phenol fibre plate which is fastened at the edge to the frame to form a cavity in back of the diaphragm. This cavity is connected to the recess in the handset handle or receiver shell by a hole in the plate. A disc of specially prepared silk covers this hole and provides the required amount of acoustical resistance. The silk fabric is so woven that it does not change in resistance with wetting and drying. The front of the unit is protected by a perforated metal grid which is assembled to the frame by means of a thin ferrule. A disc of impregnated silk is mounted between the grid and the frame to form a screen which prevents the transfer of foreign material from the front to the back of the diaphragm when the receiver is dropped. The grid and ferrule are anodically finished to resist corrosion. The spring contact surfaces are silver plated.

Prior to the introduction of this unit the receivers in general use for telephone purposes in this country and abroad employed simple resonant diaphragms and as a result had response characteristics which were characterized by prominent resonance peaks. As a rule the peak due to the first overtone, as well as that due to the fundamental resonance, fell within the important frequency range. This resonance not only introduced frequency distortion but increased the intensity with which circuit disturbances such as clicks were reproduced. Furthermore, the diaphragms of these receivers were rigidly clamped between surfaces which differed in temperature coefficients of expansion

and heat capacities from those of the diaphragm with the result that the performance of the receiver was erratic and at a given time was dependent upon the temperature changes to which it had been subjected.

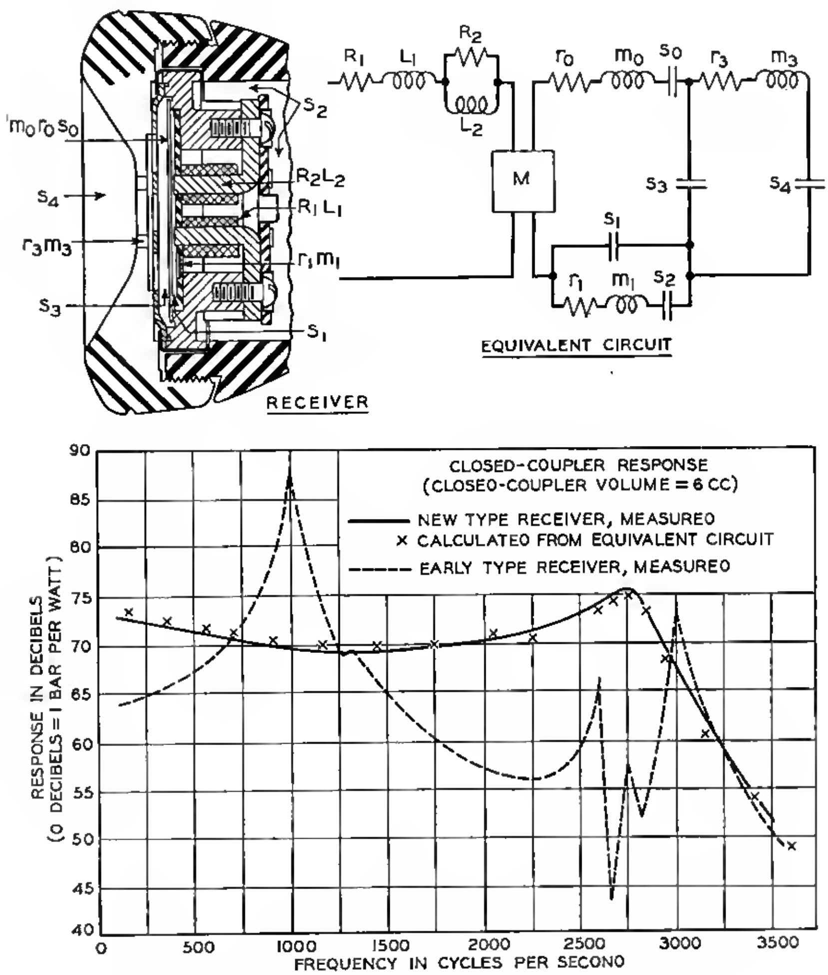

Fig. 8—Closed coupler response characteristics of the receiver.

The new receiver is so designed that:

1. All prominent resonances within the important frequency range have been eliminated and the response within this range materially improved.
2. The effect of changes in temperature has been eliminated.

3. These improvements have been accomplished without sacrificing simplicity of design or introducing features which complicate manufacture of the receiver or increase the maintenance required.

Response.—An equivalent electrical circuit for the receiver and a typical closed coupler response curve are shown on Fig. 8. Referring to this figure it will be noted that there are two meshes in the circuit which contain mass, stiffness and resistance and which control the motion of the diaphragm. One of these meshes consists of the acoustical resistance, m_1r_1, coupled to the diaphragm, $m_0s_0r_0$, by the stiffness, s_1, of the cavity between the diaphragm and the plate which surrounds the pole tips. Included in this mesh is the stiffness, s_2, of the cavity in the handset handle or receiver shell. The other mesh is composed of a cap grid, m_3r_3, and the load, s_4, coupled to the diaphragm by means of the cavity stiffness, s_3. The grid of the receiver unit proper is provided for mechanical protection only and has holes large enough to have no reaction on response. The mass of the resilient screen is small and is lumped with the diaphragm mass, m_0. The electrical portion of the circuit consisting of the winding, R_1L_1, and the equivalent eddy current circuit, R_2L_2, is coupled to the mechanical and acoustical portion by means of the force factor $M\Gamma$.

The response computed from the equivalent circuit for a number of frequencies is included on Fig. 8. The agreement between this curve and the measured curve is excellent and makes it possible to predetermine the response of the receiver with a high degree of accuracy, and to evaluate the effect on the overall response of the receiver of changes in the constants of the component parts. This type of analysis also has been invaluable as an aid in establishing the causes of variations in response which have been observed during the development and production of the receiver. A measured response curve of a receiver of the earlier type has been added to Fig. 8 for convenience of reference. The improvement in uniformity and range of response is obvious. It will be noted that large gains have been effected for frequencies in the range from 1500 to 3000 cycles per second.

The response of the receiver to a square topped wave affords an excellent measure of frequency distortion. Oscillographic records of the output of typical receivers of the new and earlier types are shown on Fig. 9 for a frequency of approximately 50 cycles per second. The distorting effect of diaphragm resonance is so obvious as to require no comment beyond pointing out that for accurate reproduction of square waves uniform response for an infinite frequency range is required and that the slight rounding of the corners of the wave as reproduced by the

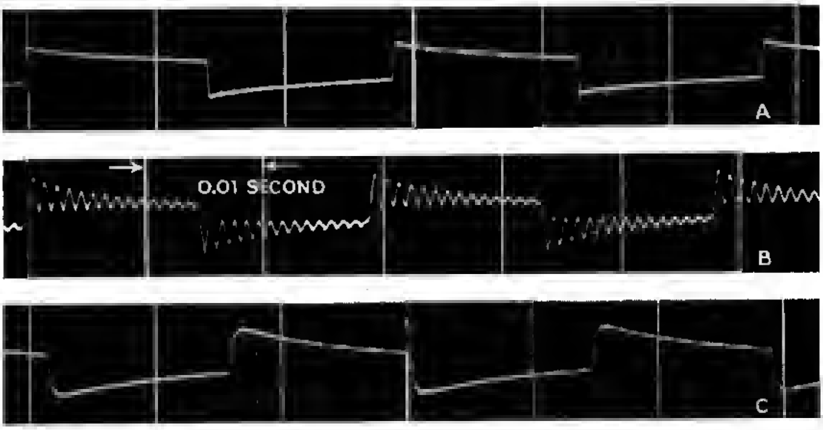

Fig. 9—Response of the receiver to square topped waves.
A—Measuring circuit—no receiver.
B—Early type receiver.
C—New type receiver.

new receiver is due primarily to the falling off of its response above 3000 cycles per second.

The substantially uniform response of the new receiver also renders clicks and other surges much less objectionable. This is due to the fact that the ear does not respond to the peak value of an oscillatory transient alone but integrates the oscillation over an interval at the beginning of the surge, hence the higher the damping the less objectionable the click.

The non-linear distortion produced by a receiver of the new type is negligible in its reaction on transmission, the harmonics in the output being 35 db or more below the fundamental.

Magnetic Circuit.—Inasmuch as the magnetic properties of the diaphragm, as well as its mechanical properties, must be considered in arriving at the preferred dimensions, it was necessary in designing the new receiver to develop criteria which could be applied in determining the optimum relationships between these factors. This study led to the use of the ratio of the force factor to the effective mass of the diaphragm for this purpose. For given magnetic materials in the pole-pieces and the diaphragm and a given air-gap length, there is a pole face area and diaphragm thickness for which this ratio is a maximum. Typical data illustrating this relationship are shown on Fig. 10. The available magnetic materials were studied using this technique and a decision was reached to use permendur in the diaphragm and 45 per cent permalloy in the pole-pieces.

There is a value of polarizing flux for which the force factor of the given magnetic circuit is a maximum. The rate at which the force factor falls off above and below this optimum value of flux is a function of the magnetic characteristics of the materials employed, the length

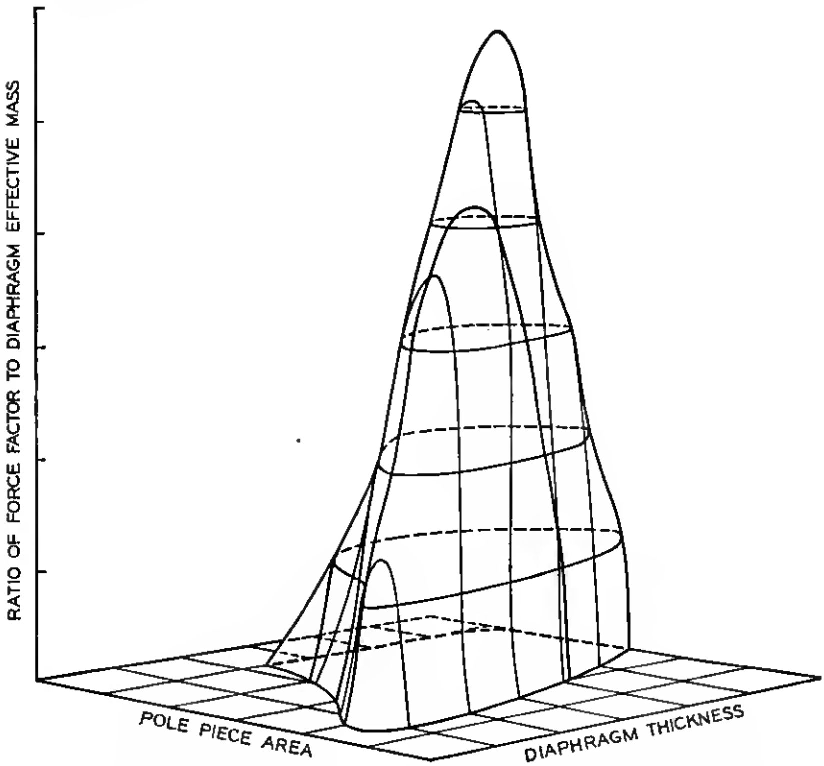

Fig. 10—Force-to-mass ratio as a function of diaphragm thickness and pole-piece area.

of the air-gaps, etc. Without exception the more efficient magnetic circuits have been found to be the most critical as regards polarizing flux. Hence, if wide variations in the efficiency of the product receivers are to be avoided and serious losses due to subsequent demagnetization in service prevented, means must be provided not only for bringing the flux in each receiver to the optimum value, but also for insuring that it remain at this value during the life of the instrument. In order to accomplish this result the magnets of the new receiver are so designed as to overpolarize the magnetic circuit when they are fully magnetized. Equipment is provided for demagnetizing each receiver to its optimum flux value during the assembly process. Receivers

which are not sufficiently overpolarized before demagnetization to resist further demagnetization under service conditions are rejected.

Temperature Effects.—The diaphragm of the new receiver is held in place by the force developed by the polarizing flux and hence it is free to expand and contract independently of its seating surface. This feature renders the performance of the receiver independent of the changes in temperature to which it has been subjected. The force due to the polarizing flux is sufficiently high to prevent rattling at input intensities many times those of loud speech.

Coupling

Although station circuits can be designed which under ideal conditions result in no sidetone, this objective is never fully realized under actual plant conditions, with the result that a part of the electrical output from the transmitter always reaches the local receiver. Whether the electrical coupling between the transmitter and receiver as evidenced by the residual sidetone is of importance from the standpoint of sustained oscillation or "howling," depends upon the degree of mechanical and acoustical coupling between the instruments. Handset and instrument design has advanced to a stage where mechanical coupling need no longer be a problem. On the other hand, as the response of the instruments is improved, the acoustical coupling may become an important item in determining the howling margin. This margin is so large under the conditions where the new handset is being used for transmission purposes that there is no tendency for oscillation or distortion to occur. However, if the handset is placed face downward on a desk or table, an air column is created which resonates in the region of 2500 cycles per second. Inasmuch as this is the region where a substantial improvement in the response of the receiver has been effected, a marked reduction in howling margin results. While there is still sufficient margin to meet all of the requirements of field use, this situation serves to emphasize the fact that such factors as acoustic coupling may limit the transmission improvements which can be effected under a given set of operating conditions.

Effective Transmission

The extent to which the better performance of the new instruments is effective in improving the grade of transmission afforded the telephone user is a complex matter and one which is influenced by such factors as the characteristics of the circuits with which the instruments are associated at a given time, the amount of noise present at the transmitting and receiving stations, the reaction of sidetone on the

loudness with which the user speaks, the distance between his lips and the face of the transmitter, the tightness with which he holds the receiver to his ear, etc. Many of these factors are beyond the control of the engineer responsible for the design of the transmitter and receiver and hence can be evaluated, insofar as their reaction on transmission is concerned, only by tests made under the conditions of actual use.

A method has been devised which makes it possible to rate the overall effect of these factors on transmission in a way representative of the results obtained by the subscribers in their normal use of the instruments.[8] Numerous tests employing this method of rating were made during the development of the new transmitter and receiver to make certain that the course followed in their development would insure the best possible performance under service conditions. Similar tests were also made of the designs selected for production. These tests show that in many respects the new instruments represent outstanding advances in transmission instrument design and performance.

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